THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

MARCH, 1957

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Effects of Radiation on Metallic Materials

AMER. INST. MINING, METALLURGICAL AND PETROLEUM ENGINEERS: 'Nuclear Metallurgy (Vol. III). A Symposium on the Effects of Radiation on Metals.' *Inst. Metals Div., Special Report* I.M.D. No. 3. Price $3·75.

The report contains the following papers:

G. H. VINEYARD: 'Theory and Mechanism of Radiation Effects in Metals', pp. 1–12.

D. E. THOMAS: 'Irradiation Effects on Physical Metallurgical Processes', pp. 13–30.

Discussion, illustrated by typical examples, of the influence of irradiation on *diffusion* (including reference to copper-nickel powder compacts), *precipitation* from solid solution (including reference to nickel-beryllium alloys), *phase transformations*, and *order-disorder changes* (including reference to the nickel-manganese system.)

D. S. BILLINGTON: 'Irradiation Effects in Reactor Materials', pp. 31–54.

Well documented review of information available on the influence of irradiation on various types of material, classified according to their respective functions in reactors. The section on structural metals and alloys includes data relating to stainless steels of various types, and nickel.

All three papers are accompanied by extensive selected *bibliographies*.

Chemical Analysis of Nickel-containing Materials

AMER. SOC. TESTING MATERIALS: '1956 Book of A.S.T.M. Methods for Chemical Analysis of Metals.' *Published by the Society*, 1956; 627 pp.

This handbook, revised from the 1953 edition, contains the full forms of all the current A.S.T.M. Standard and Tentative-Standard methods for chemical analysis of ferrous and non-ferrous metals and alloys, including procedures for spectrochemical analysis. It is essentially a part of the Book of A.S.T.M. Standards, 1956 edition.

Sections on general recommended practice and on sampling methods are followed by groups of specifications covering chemical analysis of ferrous and non-ferrous materials, methods of spectrochemical analysis, and microchemical analysis. Schedules of particular interest in relation to nickel include methods for determination of nickel in iron and steels, and analysis of nickel-chromium-(iron) alloys, nickel-copper alloys, copper alloys containing nickel, and electronic nickel. Determination of nickel in some other non-ferrous materials is also covered, e.g., in aluminium alloys.

Tensile Testing of Materials: Standard Methods

BRIT. STANDARDS INSTN.: 'Tensile Testing of Metals. *B.S.* 18: 1956; 24 pp. Price 4/-.

This is the fifth revision of the standard first published in 1904. A number of alterations have been introduced (from the fourth edition published in 1950), and the aim has been to 'describe and define all procedure relating to tensile testing which is common practice throughout industry, or any large branch of industry, but to avoid detailed description or definition of procedure which is related to specific materials.' An appendix sets out a comparison between the symbols used in this British Standard and those adopted by the International Organization for Standardization.

Adhesion Testing of Metallic Coatings

See abstract on p. 36.

Constitution of Alloys: Literature Survey, 1955

See abstract on p. 38.

NICKEL

Nickel Supplies and the Uses of Nickel

'The Supply of Nickel.'

Financial Times '*Metals in Industry*' *Survey*, Dec. 1956, p. 39.

Statistics on world production of nickel, by countries; discussion of current shortage of supplies, and of new and expanded mining enterprises which are likely to improve the position.

See also—

'Developing the Uses of Nickel', *ibid.*, p. 40.

U.S. stockpiling as a factor affecting development; the importance of nickel in industry, with special reference to stainless and other alloy steels.

Chemisorption of Gases on Nickel

P. M. GUNDRY and F. C. TOMPKINS: 'Chemisorption of Gases on Nickel Films. Part 1. Kinetic Studies.' *Trans. Faraday Soc.*, 1956, vol. 52, Dec., pp. 1609–18.

The kinetics of the sorption of hydrogen and of carbon monoxide on metal films was investigated, under various conditions, at temperatures below 195°K. (−78°C.), using nickel films pre-sintered at temperatures below 300°K. (27°C.). The results generally confirm conclusions previously drawn from experiments on sorption of the same gases by evaporated iron films, *viz.*, that the slow rate of sorption

is due to an activated diffusion process over the non-uniform surface of the metal film. Some new results now reported suggest, however, the need for certain modifications in the theory. Attention is directed to the fact that the conclusions drawn with regard to the slow process differ from those advanced by BEECK *et al.*, references to whose work is given in the *bibliography* supporting the present paper.

R. M. DELL, D. F. KLEMPERER and F. S. STONE: 'Thermal Effects in the Chemisorption of Oxygen on Nickel: a Comparative Investigation, using Powders and Evaporated Films.'

Jnl. Physical Chemistry, 1956, vol. 60, Nov., pp. 1586–8.

The studies reported indicate that, in addition to cleanliness, other factors contribute markedly to variations in behaviour. Among these variables are temperature, pressure and porosity, and, especially, dissipation of the heat of adsorption. The work on powders is reported at some length: the results on evaporated nickel films are dealt with only shortly, pending fuller publication elsewhere.

Effect of Annealing on Density of Nickel

L. M. CLAREBROUGH, M. E. HARGREAVES and G. W. WEST: 'Density Changes during the Annealing of Deformed Nickel.'

Philosophical Magazine, *8th Ser.*, 1956, vol. 1, June, pp. 528–36.

The work reported supplements earlier investigations in which release of stored energy during annealing of plastically deformed nickel was correlated with changes in hardness and electrical resistivity (*Proc. Roy. Soc.*, *A*, 1955, vol. 232, p. 252). Deformation in torsion and in compression was carried out in the manner described in the previous paper. Change in density was observed as a function of temperature up to 900°C., on specimens deformed to various degrees.

Sub-Structure/Tensile Relationships in Nickel

See abstract on p. 38.

Effects of Radiation on Metallic Materials

See abstract on p. 30.

Gas-Permeability of Electrodeposited Nickel

See abstract on p. 34.

Nickel Coinage

'New Indian Coinage.'

Metal Bull., 1956, No. 4155, Dec. 21, p. 23.

The introduction of decimal coinage in India in 1957 marks a new phase in the currency and coinage of that country. The Indian rupee in its present form was first coined in 1835, having a weight of 180 grains troy. On April 1, 1957 new coins of the denomination of 1 Naya paise and 25 and 10 Naye paise will be put into circulation. Details of the new coinage are given below:—

Coin	*Composition*
Rupee (100 Naye paise)	Nickel
½ ,, (50 ,, ,,)	,,
¼ ,, (25 ,, ,,)	,,
10 Naye paise	75-25 Cupro-nickel
5 ,, ,,	,, ,, ,,
2 ,, ,,	,, ,, ,,
1 Naya	Bronze (Cu 97, Zn 2½, Sn ½%)

Nickel Wires: Properties and Uses

See abstract on p. 39.

Stress Corrosion in Hydrofluoric Acid

See abstract on p. 45.

Nickel-Oxide Electrodes

G. W. D. BRIGGS and K. F. W. WYNNE-JONES: 'The Nickel-Oxide Electrode. Part 3.'

Trans. Faraday Soc., 1956, vol. 52, Sept., pp. 1272–81.

This paper reports one stage of a research on the electrochemical behaviour of nickel-oxide electrodes in alkaline solution: for earlier paper see *ibid.*, 1955, vol. 51, pp. 1433–52; abstract in *Nickel Bulletin*, 1956, vol. 29, No. 1, p. 7.

In the course of this work it became necessary to examine the solid reaction products by X-ray diffraction, in order to supplement the results of chemical analysis for nickel and available oxygen, and to achieve a more complete identification of the oxides. The results of these investigations are now reported. The paper also includes an account of observations made on the behaviour of $Ni(OH)_2$ deposits after ageing in aqueous solution, and of NiO deposits on nickel.

Chemical Analysis of Nickel-containing Materials

See abstract on p. 30.

Simultaneous Determination of Nickel and Cobalt

R. D. WHEALY and S. O. COLGATE: 'Spectrophotometric Method for Simultaneous Determination of Nickel and Cobalt.'

Analytical Chemistry, 1956, vol. 28, Dec., pp. 1897–8.

Aqueous solutions of nickelous and cobaltous nitrates react completely with excess diethylenetriamine, to form coloured complexes (nickel, violet; cobalt, yellow). Light-absorption properties of these complexes permit quantitative determination of both nickel and cobalt, in the absence of interfering ions. The influence of copper, chromium and manganese, which interfere, and of iron and tin, which can be removed in course of analysis, is discussed. Aluminium, zinc and lead do not interfere.

Determination of Nickel in Cadmium-Plating Solutions

H. R. FRIEDBERG and M. L. LEVY: 'Spectrochemical Determination of Nickel in Bright Cadmium Plating Solutions.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 94–6.

Nickel may be present in bright cadmium-plating solutions in the range 0·005–0·03 oz./gal. (0·0375–0·225 g./L.). The small amounts of nickel present preclude the use of analytical procedures such as are normally used for estimation of the constituents of plating baths. This paper gives full details of a spectrochemical method, including experimental data associated with its development. With the object of obtaining fast as well as accurate determinations, a macro constituent of the solution, sodium, was chosen as an internal standard. Procedure for the preparation of the standards is included in the paper.

ELECTRODEPOSITION AND OTHER COATING METHODS

Effect of Aluminium and Manganese in Nickel-Plating Solutions

D. T. EWING, A. J. SMITH and W. O. DOW: 'Effects of Impurities and Purification of Electroplating Solutions. 1. Nickel Solutions. 9. The Effect and Removal of Aluminum.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 44–6.

Report issued under the aegis of A.E.S. Project No. 5.

The basis metal used was low-carbon steel strip. Electrodeposits were prepared from pure solutions of four basic types: grey deposits from Watts-type solutions, pH 2·2 and 5·2; bright deposits from a solution of the nickel-cobalt type and from an organic bath containing nickel benzene disulphonate and triaminotolyldiphenylmethane. These deposits were compared with coatings produced from the same baths to which varying amounts of aluminium had been added. The effects produced by the presence of aluminium in the solutions are summarized below:

Appearance was assessed by examination of the plated panels under a diffused light. Over the range of aluminium concentration studied (up to 100 mg./L.), no change occurred in the appearance of the deposits produced from the Watts 2·2 pH bath, or from the bright solutions. Addition of 10 mg./L. of aluminium lightened the colour of the deposits from the Watts 5·2 pH solution, after which no change was observed until 100 mg./L. of aluminium was present: at that stage there was a considerable darkening, possibly caused by the occlusion of small amounts of colloidal aluminium hydroxide. With all four solutions, more wetting agent was required to prevent pitting when aluminium was present.

Adhesion was not affected by the presence of the aluminium in the solutions, and tests made by creasing the electrodeposited foil stripped from the panels revealed no marked effect of aluminium on ductility. Hardness measurements showed two distinct trends: aluminium in solution decreased the hardness of the nickel-cobalt deposits and increased that of the organic type. The effect of aluminium on throwing power was apparent in the Watts-type solutions, but varied considerably according to the concentration of aluminium present. In the organic solution the presence of aluminium at any concentration caused little change in throwing power. Results obtained in salt-spray testing were somewhat erratic, due, it is believed, rather to the nature of the test than to the actual influence of the aluminium additions. Report on this aspect of the subject is therefore withheld pending adoption of a test method less subject to error.

Two methods for *removal of aluminium* were studied: high- and low-current-density electrolysis, and the high-pH precipitation of aluminium hydroxide from the solution by addition of nickel carbonate. In both series of tests normal operating temperature (55°C.) was used. Electrolytic procedures proved completely ineffective: no change in equilibrium concentration occurred over long periods of electrolysis. Precipitation of aluminium is complete at pH values above 5·0, and at about pH 4·5 all but 10 mg./L. is removed. This method is thus very effective.

See also—

A. J. SMITH and R. J. ROWE: '1. Nickel Solutions. 10. The Effect and Removal of Manganese', *ibid.*, pp. 46–9.

In this section of the investigation the types of basis solution used were similar to those used in the study of the influence of aluminium. The manganese additions were at the following levels: 5, 20, 80, 160 and 300 mg./L. The influence of manganese was evaluated by the same methods as those referred to in the previous report.

With the Watts-type solutions increasing concentration of manganese had a smoothing influence on the high-current-density areas of the test panels: no effect of manganese could be observed with the nickel-cobalt or organic bright-plating solutions. Adhesion was unaffected by manganese additions, within the range studied. Increase in ductility was observed in deposits made from manganese-containing Watts pH 2·2 solutions, but the ductility of deposits made from the pH 5·2 solutions of that type and from the nickel-cobalt solution decreased with increasing manganese in the bath. No relation between manganese content of the bath and ductility could be established for the organic bright-nickel deposits. Slight variations in hardness as a function of manganese content of the solutions were insufficient to establish any definite trend, and throwing power showed no relationship to the manganese present. Corrosion-resistance of the deposits was unaffected.

For *removal of manganese* low-current-density electrolysis and high-pH precipitation methods were studied, but neither proved successful.

Gas Content of Nickel-Plating Solutions

W. M. TUCKER and F. O. BEUCKMAN: 'Dissolved Gases in Plating Baths.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 118–22.

This report is in two parts, dealing, respectively, with the influence of gases in nickel-plating and other plating solutions, and with apparatus for determination of the gas contents of such electrolytes.

The investigations reported have confirmed that plating baths contain appreciable quantities of dissolved gases, and that these gases, when they reach or exceed their combined solubility, cause pits to form on the cathode. Pitting of nickel deposits may be controlled by continuously degassing a portion of the electrolyte, so that the total gas content of the solution remains well below the combined solubilities of the gases present.

Gases dissolved in plating solutions may be determined by means of the VanSlyke blood-gas analyzer, which is described.

Increasing the Hardness of Coatings Deposited from Sulphamate Solutions

I. L. NEWELL: 'A Study of the Effect of Several Organic Addition Agents on the Hardness and Residual Stress in Nickel Deposits.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 101–4.

In the investigations reported, a sulphamate solution of the following composition was used as base:—

	g./L.
Nickel sulphamate ..	250
Sodium chloride	10
Boric acid	15
Sodium lauryl sulphate ..	0·15
Surface tension, 25°C. 40·6	
pH, 25°C. .. .. 5·0	

Such a solution was known to deposit coatings showing a relatively low degree of internal stress, and attempts were made to increase hardness by the addition of various organic agents. Preliminary tests indicated the potential usefulness of naphthalene 1,3,6, trisulphonate, saccharin, and paratoluene sulphonamide, and these media were employed for the tests reported. Effect of current density, on stress and hardness of deposits made from the modified solutions, are shown for baths containing varying amounts of the respective addition agents, and operated at various temperatures. Under favourable conditions hardnesses of more than 550 Vickers can be obtained, with compressive stress higher than 5,000 p.s.i. Deposits having such properties are satisfactorily ductile.

Electroforming of Nickel

D. S. CARR: 'Nickel Electroforming.'

Plating, 1956, vol. 43, Dec., pp. 1422–9.

This paper constitutes a monograph on the subject: much practical information is summarized, in clear and easily accessible form, and the review is supported by reference to the major literature. The material presented is classified as shown below:

Historical notes on the development of the electroforming process

Requirements which must be satisfied by the moulds (mandrels or matrices) used in electroforming
(Texture, electrical conductivity, surface finish, dimensional stability, separability)

Design of electroforming moulds and their fabrication
(including a list showing the types of material used for (*a*) permanent, and (*b*) expendable moulds)

Preparation of moulds for building-up with nickel
(Cleaning, acid-dipping, passivating, etc.)

Selection of the nickel-plating solution,
to give, in the electroformed objects, the physical and mechanical properties required for specific applications

Building up of nickel on the mould
(Some typical problems arising in electroforming are discussed, e.g., non-uniformity of thickness, high internal stress, poor throwing power, pitting, splitting of the nickel on the mould, wrinkling, burning, and the occurrence of unplated areas. Suggestions are made with regard to obviating or overcoming defects)

Improvements in plating baths used for electroforming of nickel
(Twelve examples are given of modifications which facilitate electroforming and improve the quality of the product. These improvements include the use of buffers, of highly soluble nickel salts, of wetting agents, stress reducers and levelling agents, and modifications in technique, such as the use of higher temperatures, increased agitation, better filtration, periodic current reversal and superimposed alternating current)

Removal of moulds from electroformed nickel parts
(Methods suitable for removal of permanent and expendable moulds)

Final machining and grinding of nickel electroforms
(Because of the relative ease with which nickel electroforms can be finished by grinding, as compared with machining, it is recommended that grinding be used wherever possible. Procedures for both methods of finishing are, however, reviewed)

Applications of nickel electroforming
(Brief general notes on the types of application for which electroformed parts are peculiarly suitable, due to the possibility of achieving complicated shapes, high surface finish, close dimensional tolerance and good mechanical strength)

In spite of the relatively high cost of electroformed parts, the process has a definite, though limited, place in industry.

Mechanical Properties of Nickel and Nickel-Alloy Deposits

H. C. CASTELL: 'Nickel and Nickel-Alloy Deposits.'
Metal Industry, 1956, vol. 89, Dec. 28, pp. 536–40.

Reprint of paper presented at 6th International Mechanical Engineering Congress, Paris, June 1956: see abstract in *Nickel Bulletin*, 1956, vol. 29, Nos. 8–9, p. 161.

Stress in Electrodeposited Coatings

R. PINNER: 'Stress in Electrodeposits.'
Electroplating and Metal Finishing, 1956, vol. 9, Dec., pp. 391–6; 1957, vol. 10, Jan., pp. 7–11.

This is a well-documented survey of information on a subject of which the literature is relatively scattered.

The review opens with a section on the theories which have been advanced with regard to the causes of stress in deposited metals, and this is followed by an illustrated description of methods used for measurement of stress. The magnitude of the stress characteristic of various types of electrodeposited metals is then considered, with discussion of the effect, on stress, of variables such as the nature of the substrate, the thickness of the coating, the composition of the solutions from which the deposits are produced (including the addition of stress-relieving agents), and variation in temperature, current density and pH. The use, as a corrective, of a.c. superimposed on d.c. is also noted. The material used to illustrate this major section of the review relates to electrodeposition of nickel under various conditions.

Cracking in chromium deposits is then considered (in relation to the presence of stress), and the influence of stress-relief heat-treatment. In conclusion, a résumé is made of information on the effects of stress on the properties of electrodeposits, with discussion of adhesion of the coating to the basis metal, cracking, corrosion-resistance, and magnetic properties. Reference is made also to the effect of electrodeposited coatings on the fatigue strength of steel, as influenced by stress in the deposit and also by other factors. The *bibliography* supporting the review comprises 55 references.

Gas-Permeability of Electrodeposited Nickel

D. T. EWING, J. M. TOBIN and D. G. FOULKE: 'Permeation of Gases through Electrolytic Nickel Deposits. II. Determination of the Effect of Several Variables on the Intrinsic Permeability of Nickel Deposits to Gases.'
Jnl. Electrochemical Soc., 1956, vol. 103, Dec., pp. 648–51.

The authors recently described a method for determining permeability of detached nickel electrodeposits (*ibid.*, pp. 545–8; abstract in *Nickel Bulletin*, 1956, vol. 29, No. 12, p. 208). The procedure described, which gives a good degree of reproducibility, is intended to give a measure of the 'porosity' characteristic of a nickel deposit made from a solution of given composition, in given plating conditions, in the absence of accidental effects such as gas pores, inclusions of particles in the deposit and pores caused by defects in the basis metal.

This second paper is concerned with influence of variables in plating, on the intrinsic gas-permeability of nickel deposits. A Watts-type solution was used, and temperature, current density and pH were independently varied: a study was made also of the effects of variation in total-nickel, chloride and boric-acid concentrations, and of the addition, to such a bath, of various brightening agents. The effects of adding small amounts of colloidal graphite, gelatin, anode sludge, Fe(III), Cu(II) and zinc, as impurities, were also included in the investigation.

The main conclusions are as follows:

At the lower pH values used in the tests decrease in concentration of the nickel salts did not exert any marked influence on permeability of the deposits, even though considerable gassing took place at the cathode. Higher pH values tended to increase permeability, an effect which, it is believed, may be attributable to colloidal basic nickel compounds formed in the solution under such conditions. The effect of reduction in the amount of boric acid was greatest in a bath operated at pH 5·2, due, possibly, to decrease in buffering action in the cathode layer, and resulting high pH values in the cathode film. Brittleness of the films increases with decrease in boric-acid content.

Little difference in permeability was observed among the deposits made from the various solutions used: those made from the Watts-type bath were, however, found to be slightly more permeable to gases than the bright deposits. It is suggested that this difference may be related to the laminar structure of nickel deposited from the bright solutions, as compared with the columnar structure characteristic of deposits made from the Watts solution.

There is no evidence of any direct correlation between permeability and corrosion-resistance. It is considered probable that accidental defects in the deposits, e.g., gas pores, and co-deposited metals such as brighteners, are more important controlling factors in the corrosion-resistance of plated articles than is the initial intrinsic permeability of the deposited coatings. The recognition of the adverse influence of impurities in the plating solutions is, however, strengthened by data reported in this paper, which demonstrate that colloidal and metallic impurities can cause very large increases in intrinsic permeability. This factor must be recognized as one of those involved in the poor corrosion-resistance found in deposited coatings produced from impure solutions.

Porous Nickel-Cadmium Electrodeposits

L. D. McGRAW, J. P. SPENARD and C. L. FAUST: 'Electrodeposition of Porous Nickel-Cadmium Alloy.'
43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 209–10.

In 1954 FAUST and SAFRANEK reported successful

electrodeposition of porous deposits of nickel, zinc and copper from solutions to which an addition of colloidal graphite had been made: see *Nickel Bulletin* 1954, vol. 27, No. 5, p. 90.

The present paper reports production of porous nickel-cadmium alloy deposits from a solution prepared by addition of cadmium sulphate to the bath recommended by Faust and Safranek for electrodeposition of porous nickel. The composition of the solution is given as:

	g./L.
$NiSO_4.7H_2O$	350
$NiCl_2.6H_2O$	45
H_3BO_3	40
Aquadag (colloidal graphite)	60
Wetting agent	
(Harshaw Chemical ..	
Company's XXXD) ..	10 ml./L.

The effect, on the composition of the deposited alloy, of variations in the cadmium-sulphate content of the bath, and of operating conditions, was investigated.

Electrodeposition of Chromium on High-Alloy Materials

C. LEVY: 'Electroplating Chromium on Unusual Alloys.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 219-22.

The aim of the work reported was the development of practical methods of depositing chromium on materials used for high-temperature service. Such coatings may enhance the usefulness of some of these materials in applications in which increased corrosion- and wear-resistance, as well as high-temperature strength, is called for. A primary requisite for successful service is good adhesion of the coating to the base, and the author studied the effect, on adherence, on twelve different preparatory cycles.

The materials used as base are shown in the table below. Nine are heat- and/or corrosion-resisting types: S.A.E. 4340 steel was used for comparison purposes:

Composition of Basis Materials

Alloy	Co %	Ni %	Cr %	Mo %	C %	Mn %	Si %	Fe %	W %	Other %
Stellite 21 ..	61·31	2·71	27·80	5·40	0·26	0·51	0·65	1·36	—	—
S-816 ..	42·18	20·25	19·92	4·10	0·35	1·27	0·52	3·11	4·37	3·90 Nb
V-36 ..	45·34	19·29	24·70	4·39	0·27	0·86	0·18	1·87	2·31	—
Hastelloy B..	—	65·48	0·07	28·30	0·05	—	—	4·36	None	—
Hastelloy C..	—	52·55	16·62	16·70	0·05	—	—	6·14	5·28	—
Inconel X ..	—	72·28	15·81	—	0·35	0·59	0·39	6·79	—	0·14 Cu
Molybdenum	—	—	—	98·85	0·04	—	—	—	—	0·99 V
502 Stainless	—	0·21	5·09	0·55	0·04	0·48	0·40	Remainder	—	—
19-9 DL Stainless	—	9·20	19·10	1·24	0·29	1·27	0·89	do.	0·11	0·09 Ti 1·03 Nb
SAE 4340 Steel	—	1·80	0·76	0·23	0·37	0·64	0·28	do.	—	—

Electrical Conductivity of Electroless Nickel Deposits

A. KEIL and B. BERGER: 'Electrical Conductivity of Chemically Deposited Nickel Coatings.'

Metalloberfläche, 1956, vol. 10, Dec., pp. 356-7.

Following some notes on the nature of the nickel-phosphorus deposits made by the electroless plating process, and on the technique of deposition, an account is given of methods used for determination of the electrical conductivity of such coatings. Results of measurements on deposits of various thicknesses, produced under various conditions, are recorded. Comparison of an average figure derived from these individual measurements, with a typical value for bulk nickel, leads to the conclusion that the electroless nickel-phosphorus coatings have about 14 per cent. of the conductivity of nickel.

The materials were in the form of $\frac{1}{8}$-in. thick discs, ranging from $\frac{7}{8}$-in. to 2-in. diameter. The surfaces of the specimens were in the as-machined condition. The cleaning procedure for each specimen consisted of vapour degreasing in trichlorethylene, and electrolytic hot-alkali treatment in a proprietary cleaner: 20 seconds anodic at 4 volts, cold-water rinse, 5 seconds cathodic at 4 volts, cold-water rinse.

The standard electroplating bath consisted of a 15-gallon aqueous solution containing 33 oz./gal. of chromic acid and 0·33 oz./gal. of sulphuric acid. The temperature of the bath was maintained at 131°F. (54°C.) and a current density of 2 amp./sq. in. was applied, using lead anodes. The thickness of chromium deposited was 0·002-0·003 in.

For the respective basis metals indicated, the plating sequences shown on p. 36 applied immediately after

the cleaning cycle described, resulted in sound deposits showing good adhesion.

'*S.A.E.* 4340 *Steel*

(1) Immerse in 50 per cent. hydrochloric acid for one minute; cold-water rinse.

(2) Immerse in chromium-plating bath for 30 seconds without current.

(3) Reverse-current etch (specimen anodic) at 1 amp./sq. in. for 20 seconds.

(4) Apply plating current at 2 amp./sq. in.

'*Molybdenum*

Same plating sequence as for S.A.E. 4340 steel.

'502 *Stainless Steel*

Same plating sequence as for S.A.E. 4340 steel.

'*V*-36 *Alloy*

(1) Immerse in 50 per cent. hydrochloric acid for one minute; cold-water rinse.

(2) Anodic treatment in Woods' solution (2 lbs. nickel chloride, 1 pint hydrochloric acid per gallon of aqueous solution; nickel electrode) at 2 volts (⅓ amp./sq. in.) for 20 seconds.

(3) Cathodic treatment in Woods' solution at 2 volts (⅓ amp./sq. in.) for 2 minutes; cold-water rinse.

(4) Immerse in chromium-plating bath for 30 seconds without current.

(5) Apply plating current at 2 amp./sq. in.

'*Inconel X*

Same plating sequence as for V-36 alloy.

'*S*-816 *Alloy*

Same plating sequence as for V-36 alloy.

'*Hastelloy B*

(1) Immerse in 50 per cent. hydrochloric acid for one minute; cold-water rinse.

(2) Immerse in hot (160°F.) concentrated nitric acid (70 per cent.) for 30 seconds; cold-water rinse.

(3) Immerse in chromium-plating bath for 30 seconds without current.

(4) Apply plating current at 2 amp./sq. in.

'19-9 *DL Stainless Steel*

Same plating sequence as for Hastelloy B or for V-36 alloy.

'*Stellite* 21

Same plating sequence as for Hastelloy B.'

Determination of Nickel in Cadmium-Plating Solutions

See abstract on p. 32.

Adhesion Testing of Metallic Coatings

J. W. BEAMS: 'Study of Adhesion by the High-Speed Rotor Technique.'
43*rd Ann. Technical Proceedings, Amer. Electroplaters' Soc.*, 1956, pp. 211–14.

This paper describes a new method of adhesion testing, evolved as a result of the development, at the University of Virginia, of a method for spinning magnetically suspended rotors in a high vacuum.

Films of the material to be tested are uniformly deposited on the peripheries of cylindrical rotors having different radii, and the rotor speeds are increased until the material is thrown off. The behaviour of the coatings under such test is used to evaluate the tensile strength of the coating and its adherence to the base.

The technique of testing is described, also the interpretation of the results obtained.

Accelerated Corrosion Testing of Metallic Surfaces

W. D. McMASTER: 'Accelerated Testing of Metallic Surfaces. The Salt-Spray Test and its Modifications.'
Metal Finishing, 1956, vol. 54, Nov., pp. 48–51, 55.

This digest is intended for use of those not normally in contact with the publications of the American Society for Testing Materials, in which very detailed reports on the subject of accelerated testing have appeared from time to time.

A critical résumé is made of the nature of the following tests, the significance of the data obtainable from them, and the validity and reproducibility of the results:

(1) The 20 per cent. Sodium-Chloride (Salt-Spray) test.

(2) The 5 per cent. Sodium-Chloride (Salt-Spray) test (covered by A.S.T.M. B.117-54T).

(3) The Acetic-Acid/Sodium-Chloride Spray Test (covered by A.S.T.M. B.287-54T).

The results given by test (3) are considered in relation to the establishment of 'performance index' ratings which can be correlated with the probable behaviour of coatings in automobile service.

In connexion with other methods which may be used for accelerated testing of metallic coatings, attention is directed to research in progress by a committee of the American Electroplaters' Society, which is at present actively studying the suitability of the acetic-acid modified salt-spray test, and of the Corrodkote test. For further details of the work of that Committee, see following abstract.

W. L. PINNER: 'Progress Report on Accelerated Corrosion Tests for the Performance of Plated Coatings.'
43*rd Ann. Technical Proceedings, Amer. Electroplaters' Soc.*, 1956, pp. 50–5.
Third Report issued under A.E.S. Research Project No. 15.

The first report (see *Nickel Bulletin*, 1954, vol. 27, No. 2, pp. 24-5) outlined the methods which were to be studied with regard to their suitability for adoption as accelerated tests for evaluation of the corrosion-resistance of electroplated coatings. The second report (see *Nickel Bulletin*, 1955, vol. 28, No. 11, p. 182) gave a critical assessment of twenty methods which had, in the interim, been examined

by the Research Project Committee. A summary was made of the nature of these tests and the extent to which they were considered to be promising or of no potential value (*loc. cit.*).

At the time of the second report six methods were under active study and some others were in a 'deferred' state. Since that date the research has been still more closely delimited and intensive attention is now being devoted to only two methods:

The acetic-acid modification of the salt-spray test, and

The Corrodkote method.

This third report opens with a résumé of the criteria which the Committee has set up for judgment of the suitability of an accelerated test; detailed consideration is then given to the two tests mentioned.

Acetic-Acid/Salt-Spray Test (covered by A.S.T.M. B.287-54T)

Although this test is more satisfactory than the neutral salt-spray method, in reproducing the type of corrosion encountered in outdoor service (particularly in the case of coatings on zinc-base die castings), its main advantage lies in the acceleration of results, and the Committee emphasizes that due consideration must be given to the many variables which can affect the results obtained by the modified procedure. To this end they make specific recommendations on precautions which should be observed in carrying out the tests: it is noted that many of these limitations in conditions supplement those laid down in the A.S.T.M. specification. With regard to the interpretation of the results of the test, optimum size of specimen and statistical methods of analysis are discussed.

The Corrodkote Test

This test (of which full details were given in the second report under this Project) consists essentially in rubbing the cleaned, finished part with a paste consisting of Kaolin and a mixture of chemical constituents selected for their ability to promote corrosion, and, after coating the part with this paste, placing it in a humidity cabinet (temperature 100°F., relative humidity about 90) for a suitable period, e.g., twenty hours. The test is virtually a reproduction of service conditions to which plated automobile parts may be subjected when covered with slush from the roads in winter and subsequently placed in a closed warm garage for the night.

To date, investigations on this test have comprised a study of more than 130 chemical mixtures with which the Kaolin may be mixed to produce a corrodent giving reproducible results comparable with those observed in outdoor service under the conditions mentioned. The mixtures used have been based, in the main, on weather data over various periods for the Detroit area, where the slush, rainfall and melted snow have been found to contain all the common acids and a very wide variety of metallic salts, among which those of copper and iron are specifically noted. A typical analysis of rainwater atmosphere for that area is given in the report.

Using the data accumulated by these means, it has been found possible, by varying the chemical solutions used with the Kaolin, to obtain types of corrosion characteristic of that occurring in many industrial and seaboard areas of the U.S.A. in which members of the Committee have had occasion to examine plated parts. The composition of a solution which appears to reproduce closely the type of corrosion encountered in Detroit in winter is given below:

Cupric nitrate	0·035 g.
Ferric chloride	0·165 g.
Ammonium chloride ..	1·0 g.
Kaolin	30·0 g.
Water	50·0 ml.

Photomicrographs in this report show corroded parts from automobiles and panels of comparably plated types, after test by the Corrodkote procedure. The close duplication of service-type corrosion obtained by this method is clearly indicated. Other figures illustrate the way in which the nature of the corrosive attack can be controlled to simulate other forms of attack encountered in service.

Investigations are in hand to check the reproducibility of results from several laboratories, the accuracy with which the relative percentage humidity must be controlled, and the relation of time of exposure in the humidity cabinet to the extent of the deterioration which occurs in the coating.

Thickness Measurement of Nickel Coatings

W. W. SELLERS and K. G. CARROLL: 'Gauging of Thin Nickel Coatings by X-ray Fluorescence.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 97–100.

Three X-ray methods may be used for measurement of the thickness of thin metallic coatings: the essential features of each procedure are outlined as an introduction to this paper. The first technique is based on intensity measurements of a diffraction line of the basis metal: absorption of the beam (monochromatic) in its double passage through the coating is a measure of thickness. For metals, however, diffraction-line intensity is sensitive to many extraneous variables (e.g., grain size, crystal orientation and state of stress), which interfere with accurate measurement. This fundamental difficulty is overcome in method 2, which utilizes fluorescent or secondary X-radiation from the basis metal and is therefore unaffected by the metallurgical state of that metal. The advantages of this method are indicated. Method 3 is based on the excitation and measurement of fluorescent X-rays in the plating metal itself. It is an emission method, in contrast to the other two methods, which depend upon absorption within the coating. It requires the use of a monochromator, to sort out the X-rays which originate within the plating and which may be used to measure its thickness. This procedure is well suited to the measurement of thin nickel coatings, and has the advantage that it can be applied by means of X-ray instruments which are widely available. It was used in the investigation described in the present paper.

Full details are given of the apparatus employed and measurements made by it are reported, demonstrating the close agreement obtained on duplicate samples and the possibility of measuring, by this method, the thickness of ultra-thin coatings.

Protection of Molybdenum against Oxidation

See abstract on p. 42.

NON-FERROUS ALLOYS

Constitution of Alloys: Literature Survey, 1955

H. SPENGLER: 'Investigations on the Constitution of Alloys, 1955.'

Metall, 1956, vol. 10, Dec., pp. 1145-9.

A classified list of references to literature published during 1955, relating to binary, ternary, quaternary and quinary alloy systems. The nickel-containing series included are shown below.

Binary: Ni-Al, -Cd, -Co, -Cr, -Fe, -Ge, -O, -P, -Pb, -S, -Sn, -Ti, -Zn.

Ternary: Ni-Al-Cu, -C-Cr, -C-Fe, -Co-U, -Cr-Cu, -Cr-W, -Fe-N, -Fe-U, -Fe-O, -Mn-U.

Nickel-Iron-Chromium-Titanium-Aluminium Alloys: Constitution

See abstract on p. 40.

Sub-Structure/Tensile Relationships in Nickel and Nickel Alloys

S. WEISSMANN: 'Quantitative Study of Substructure Characteristics and Correlation to Tensile-Property of Nickel and Nickel Alloy.'

Jnl. Applied Physics, 1956, vol. 27, Nov., pp. 1335-44.

Considerable interest has been evinced during the past few years in the relationship between the substructure formation resulting from the deformation of metals and their mechanical properties. Investigations on nickel and on nickel-titanium alloys have shown that increasing amounts of room-temperature deformation, followed by recovery, caused a regular gain in strength and that such change was accompanied by a linear increase in substructure density: see abstract in *Nickel Bulletin*, 1954, vol. 27, No. 11, p. 209.

Recent X-ray investigations have revealed that various orders of magnitude of substructural entities co-exist and it is the purpose of the paper now published to present qualitative and quantitative data relating these various orders of substructural entities to the strength properties of metals. Nickel, and nickel binary alloys with titanium (1 per cent.) and with cobalt (20 per cent.) were used, and the studies were carried out by means of a newly developed sensitive technique combining X-ray microscopy and diffraction analysis. (This technique has been fully described, *ibid.*, 1956, vol. 27, pp. 389 *et seq.*)

Titanium-Nickel Alloys

T. ARAKI: 'The Heat-Treatment of Titanium-Nickel Alloys.'

Jnl. Mechanical Laboratory, Japan, 1956, vol. 10, No. 2, pp. 74-7.

Study of effects obtainable, by various forms of heat-treatment, in binary alloys containing 2-12 per cent. of nickel. The main observations made are summarized in *Metallurgical Abstracts*, 1956, vol. 24, Nov., p. 156.

Diffusion in Nickel-Gold Alloys

J. E. REYNOLDS, B. L. AVERBACH and M. COHEN: 'Self-Diffusion and Interdiffusion in Gold-Nickel Alloys.'

Acta Metallurgica, 1957, vol. 5, Jan., pp. 29-40.

Report of measurement of self-diffusion and interdiffusion coefficients as functions of composition and temperature. The data obtained are combined with the thermodynamic properties of alloys of the system, to test the validity of the equation derived by Darken to express quantitative relationships between the intrinsic and interdiffusion coefficients (*Trans. Amer. Inst. Min. Met. Eng.*, 1948, vol. 175, p. 184).

Nickel Silvers: Data Sheet

J. L. EVERHART: 'Nickel Silvers.'

Materials and Methods, 1956, vol. 44, Dec., pp. 117-32. *M. and M. Manual* No. 133.

This manual covers (*a*) wrought nickel silvers (nickel brasses) containing 18-10 per cent. of nickel, with varying amounts of copper and zinc, with or without small amounts of lead; (*b*) 18 per cent. nickel nickel silvers used in powder-metallurgy products, and (*c*) leaded nickel brasses and nickel bronzes (12-25 per cent. nickel) used in the form of castings.

Sections of the survey contain, respectively, summarized information on the physical and mechanical properties of the alloys (including sub-zero and elevated-temperature properties), fatigue characteristics, corrosion-resisting properties and fabrication. Methods recommended for working, heat-treatment, welding and surface-finishing of the alloys are reviewed. Typical applications for which the various grades are in established use are described and illustrated.

Nickel-base Sparking-Plug Alloys

HENRY WIGGIN AND CO., LTD.: 'Silicon-Manganese-Nickel Alloys.'

Publn. 1179*, 1956; 4 pp.

Sparking plugs of modern internal-combustion engines operate in conditions involving severe high-temperature corrosive-erosive attack, resulting from the combustion products of anti-knock fuels at the

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high compression ratios now employed. High-temperature corrosion, by lead and sulphur present in the fuel, can be extremely destructive, especially if combustion conditions are reducing, and although it can be to some extent minimized by suitable design of the plugs, the use of special materials is essential.

This publication describes the properties of three alloys which have proved particularly suitable for sparking-plug electrodes. All are nickel-base materials, containing silicon and manganese: the ratio of the two addition elements is varied to suit the plug designs of individual manufacturers.

The approximate compositions are shown below:

Table I

Essential Elements	W.5 %	W.6 %	W.7 %
Manganese ..	0·3	0·5	2·75
Silicon ..	4·0	2·0	1·0
Nickel ..	Bal.	Bal.	Bal.

This publication gives typical physical and mechanical properties for the three alloys. All can be used for centre and earth electrodes, on all types of sparking plug. They can be successfully projection welded and spot-welded to the steel body of the plug. The alloys are produced in the form of wire, strip, or rolled tape, in various tempers.

Corrosion by Naphthenic Acid

See abstract on p. 46.

Stress Corrosion in Hydrofluoric Acid

See abstract on p. 45.

Nickel-Alloy Wires: Properties and Uses

D. SCHMID: 'Selecting Nickel-Alloy Wire.'
Materials and Methods, 1956, vol. 44, Dec., pp. 100–5.

Three groups of non-ferrous nickel-base alloys are of interest as spring materials: (1) Monel, R Monel and K Monel; (2) Nickel, Duranickel and Permanickel, and (3) Inconel, Inconel X and Inconel W. This article gives tabular and graphical information on the properties of these materials, in wire form of various tempers, and discusses some of the applications for which the respective materials are particularly well suited.

Welding of Nickel-Aluminium-Bronze Propellers

J. L. CAHILL: 'Welding of Nickel-Aluminum Bronze.'
Welding Jnl., 1956, vol. 35, Dec., pp. 1226–30.

For many years manganese bronze has been generally used for propellers of both Naval and merchant ships, but recently there has been a turnover, by many shipbuilders, to an alloy containing aluminium 9–10, nickel 5, iron about 5, per cent. This type of material is being used, in both the U.K. and the U.S.A., under various trade names.

Repair-welding procedure has been well established for manganese bronze, and full qualification test data have been obtained from a standardized test specimen simulating a major repair to a propeller. This paper reports experiments made to provide similar information for welding of the nickel-aluminium bronze.

The information given shows that castings of such material can be successfully welded by means of the inert-gas-shielded metal-arc process, using aluminium-bronze filler wire. It is considered that this method may satisfactorily be used for repairs. To date, welds made with nickel-aluminium bronze filler wire have proved brittle, and have shown a tendency to cracking, but work is in progress with a view to modification of the filler-wire composition (reduction of aluminium content) to produce higher-strength, ductile welds.

Monel and R Monel: U.S. Federal Specification

'Nickel-Copper Alloy (Monel and R Monel) Bars, Plates, Rods, Sheets, Strips, Wire Forgings, and Structural and Special Shaped Sections.'
Federal Specification QQ-N-281a, Feb. 7, 1956; 18 pp.
Published by *Superintendent of Documents, U.S. Government Printing Office, Washington* 25, D.C., U.S.A.

The specification covers chemical requirements, thermal treatment, mechanical properties, permissible variations in dimensions, sampling and test procedure, packaging and marking of material of the forms detailed, in alloys within the compositions shown below.

The schedule also includes notes on the types of application for which the two materials, in various forms, are suitable, and of stress-relief treatment recommended for cold-drawn wire springs.

Ni* %	Fe (max.) %	Al (max.) %	Mn (max.) %	C (max.) %	Si (max.) %	S %	Cu %
63–70	2·50	0·5	2·0†	0·3	0·5	0·024 (max.)	remainder
63–70	2·50	0·5	2·0	0·3	0·5	0·025–0·060	,,

* Cobalt counting as nickel
† For plate, sheet and strip manganese shall be 1·25 per cent. max.

Nickel Coinage

See abstract on p. 31.

Chemical Analysis of Nickel-containing Materials

See abstract on p. 30.

NICKEL-IRON ALLOYS

Constitution of Alloys: Literature Survey, 1955

See abstract on p. 38.

Magnetic Characteristics of Thin Nickel-Iron Films

C. A. FOWLER, E. M. FRYER and J. R. STEVENS: 'Magnetic Domains in Evaporated Thin Films of Nickel-Iron.' *Physical Rev.*, 1956, vol. 104, Nov. 1, pp. 645-9.

It has been recognized for some years past that the examination of thin films of ferromagnetic materials offers considerable promise as a means of elucidating certain problems of magnetic theory which are difficult to interpret from bulk material. Interest in thin films has been heightened by the possibility of their utilization in magnetic information-storage devices.

This paper reports use of the longitudinal Kerr magneto-optic technique for observation of domains in evaporated 80-20 per cent. nickel-iron alloy films ranging in thickness from 20,000 to 500 Å. Domain patterns were photographed in all but the two thickest films: the paper is well illustrated with typical results. Many features of domain structure which are familiar in bulk single crystals were observed in the films, but some unusual features of domain behaviour appear to be characteristic of films of the thinnest sizes examined. Complexities observed in many of the patterns, which could not be correlated with change in thickness of film, are considered to be due to uncontrolled physical factors associated with manufacture and preservation of the specimens. The necessity for rigid control of all conditions when preparing specimens for quantitative domain investigation is emphasized.

CAST IRON

Chemical Analysis of Cast Irons

See abstract on p. 30.

Relaxation Properties of Cast Iron

See abstract on p. 41.

CONSTRUCTIONAL STEELS

Relaxation Properties of Steels

See abstract on p. 41.

Corrosion by Naphthenic Acid

See abstract on p. 46.

Ferritic-Austenitic Weld Joints in Steam Plant

See abstract on p. 43.

Chemical Analysis of Nickel-containing Steels

See abstract on p. 30.

HEAT- AND CORROSION-RESISTING MATERIALS

Nickel-Iron-Chromium-Titanium-Aluminium Alloys: Constitution

A. TAYLOR: 'Constitution of Nickel-Rich Quinary Alloys in the System Ni-Fe-Cr-Ti-Al.' *Jnl. of Metals*, 1957, vol. 9, Jan.; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 72-5. T.P. 4374E.

This paper is a further contribution to the series in which the author has reported studies of simple and complex nickel-chromium-base alloys: for reference to earlier papers see *Nickel Bulletin*, 1957, vol. 30, Nos. 1-2, p. 10.

In this investigation of nickel-rich quinary alloys attention was confined to the 750° and 1000°C. isothermals of the pseudo-quaternary section Ni_3Cr-Ni_3Fe-Ni_3Ti-Ni_3Al. 'Only three phases are involved: the nickel-rich face-centred-cubic primary γ-solid solution, the ordered face-centred-cubic γ' phase based on Ni_3Al, and the hexagonal-close-packed η-Ni_3Ti. The ternary face, Ni_3Fe-Ni_3Al-Ni_3Ti, of the pseudo-quaternary tetrahedron is very similar to the ternary face Ni_3Cr-Ni_3Al-Ni_3Ti, because of iron replacing chromium, atom for atom, in the two face-centred-cubic phases, γ and γ'. The extent of the γ-solid solution increases considerably as the temperature is raised, while γ' and η remain substantially unchanged. The tie-lines linking the γ and γ'-phases radiate uniformly across the $\gamma+\gamma'$ two-phase field of the pseudo-quaternary tetrahedron. Alloys situated near the Ni_3Fe corner of the tetrahedron are strongly ferromagnetic. The boundary separating the magnetic from the non-magnetic γ-phase alloys at room temperature is defined by a plane lying parallel to the Ni_3Cr-Ni_3Ti-Ni_3Al face of the system and containing chromium and iron in the atomic ratio 60 : 40.'

Intermetallic Phase in High-Titanium Austenitic Steels

W. KOCH and C. ILSCHNER-GENSCH: 'Intermetallic Phase showing α-Manganese Structure, found in Austenitic Chromium-Nickel-Molybdenum Steels of High Titanium Content.' *Archiv f.d. Eisenhüttenwesen*, 1956, vol. 27, July, pp. 453-7.

The compositions of the two steels examined are shown in the table below:

Steel	C %	Si %	Mn %	Cr %	Mo %	N %	Ni %	Ti %
A	0·02	0·89	0·97	16·8	0·99	0·044	9·64	3·07
B	0·02	1·37	1·05	16·2	1·87	0·017	9·45	3·44

An unknown intermetallic phase, observed in both steels, showed the α-manganese type of structure. Analysis of specimens electrolytically separated from the steel gave titanium and molybdenum contents much higher than those of the parent steel, and indicated that iron, chromium and nickel were also present. On heating at 1100°C. and above the phase is dissolved in the groundmass of the steel. In steel B, which had a titanium content still higher than that of steel A, Fe_2Ti was present in association with the newly observed phase. The Fe_2Ti was more stable than the high-molybdenum-titanium phase, persisting, as the sole intermetallic compound, at temperatures above 1200°C.

Recrystallization of Nickel-Chromium-Iron Alloys

H. KOFLER-VALENCAK and H. KRAINER: 'Investigation of Recrystallization Phenomena in Nickel-Chromium and Nickel-Chromium-Iron Alloys.'

Archiv f.d. Eisenhüttenwesen, 1956, vol. 27, Nov., pp. 725–30.

Report of studies on two standard electrical-resistance alloys, 80–20 nickel-chromium and 30–20 nickel-chromium-iron, both conforming to D.I.N. Specification 17 470. Full details of the composition of the two materials are given. The specimens were examined in the form of wires, cold-drawn to 5, 10, 20, 40, 60 and 80 per cent. reduction and annealed at temperatures up to 1100°C. for periods varying from 15 minutes to 8 hours.

Mechanical properties (tensile strength and percentage elongation at fracture), and electrical resistance were studied as functions of the condition and treatment of the wires, and the structures characteristic of the respective conditions were also examined. Results are shown in a series of graphs and photomicrographs.

The data presented demonstrated that the effects of cold-working and annealing on mechanical properties and structure of the two alloys are in accordance with those normally observed in alloys treated in the manner described. Recrystallization studies show closely parallel effects in the two materials, but recrystallization sets in at somewhat higher temperatures in the iron-containing than in the 80–20 nickel-chromium alloy, e.g., the heavily cold-worked 80–20 alloy shows evidence of recrystallization after annealing at 600°C., but a temperature of 700°C. was required to produce incipient recrystallization in the 30–20 nickel-chromium-iron alloy.

Particular attention is directed to apparent anomalies in the influence of cold-working and annealing on the electrical resistance of the alloys. In the 80–20 type cold-working resulted in a marked fall in electrical resistance, and the 30–20 nickel-chromium-iron alloy was affected in the same sense, but to a lesser degree.

A large proportion of the initial electrical resistance was recovered after annealing at 300°–400°C.: five minutes at 400°C. sufficed to restore it to the initial value, and treatment at 500°C. resulted in still further rise. Electrical resistance was studied also in relation to the influence of rate of cooling from the annealing temperature. In connexion with the anomalies observed in the electrical-resistance properties, reference is made to the work of TAYLOR and HINTON (*Jnl. Inst. Metals*, 1952–53, vol. 81, pp. 169–80: *Nickel Bulletin*, 1953, vol. 26, Nos. 1–2, p. 10).

Relaxation Properties of Steels and Alloys

J. W. FREEMAN and H. R. VOORHEES: 'Relaxation Properties of Steels and Super-Strength Alloys at Elevated Temperatures.'

Amer. Soc. Testing Materials, Special Tech. Publn. No. 187, 1956; 97 pp.

The report is one of a series prepared under the auspices of the Data and Publications Panel of the A.S.T.M./A.S.M.E. Joint Committee on Effect of Temperature on the Properties of Metals. The information presented consists of a correlation of data obtained from fifteen organizations engaged on creep testing, (who were approached by the Committee specifically in connexion with this compilation), and of information obtained from other sources.

As used in this report, the term 'relaxation' signifies the replacement of an initial elastic strain by the plastic strain of creep, with consequent reduction in level of stress. The relaxation strengths tabulated are the residual elastic stresses remaining after relaxation for time periods of 100, 500, 1,000 and 10,000 hours: in some cases data for 10-hour relaxation strengths are also given. The temperatures covered range, in most cases, from 750° to 1100°F. (400° to 595°C.) and for super-strength high-temperature alloys some data at 1200° to 1500°F. (650° to 815°C.) are added. The types of material covered in this reference manual are shown below:

Carbon steel wires: room-temperature tests
Carbon-molybdenum steel
Chromium-molybdenum steels of various types, and modified chromium-molybdenum steels
Low-alloy steels containing 1–3 per cent. of nickel
Molybdenum-vanadium steels
Chromium-silicon-molybdenum-vanadium steels
Chromium-molybdenum-vanadium steels
Chromium-tungsten-vanadium steels
Stainless steels (12 per cent. chromium and 18–8 chromium-nickel types)
Chromium-nickel-iron-base alloys
Cobalt-base high-temperature alloys
Nickel- „ „ „ „
Iron- „ „ „ „
Cast irons: short-time tests.

Chemical compositions, heat-treatments, mechanical properties at room temperature, and, in some cases, creep properties, are shown in association with the relaxation values.

Creep in Stainless-Steel Tubing

M. J. MANJOINE: 'Creep Characteristics of Type 347 Stainless Steel at 1050° and 1100°F. in Tension and Compression.'

Amer. Soc. Mechanical Engineers Paper 56-*A*-40; 8 pp.

Most published data for niobium-stabilized 18–8 stainless steel are for bar stock: the tests reported in

this paper were made on specimens machined from cold-drawn and stress-relieved seamless tube.

Tensile creep tests (made in a conventional machine, at several stress levels) show that the creep characteristics of the material are unusual: after a very short stage in which creep rate is very high, it drops to a very low value, and this abnormally low rate continues for a period which is an inverse function of the stress and/or the initial strain, i.e., the period of abnormally low creep rate increases as the test stress is lowered. The material thus appears to go through an 'ageing' period, during which it is strengthened to a very creep-resistant state. After the ageing period a second period of higher constant creep rate is observed, followed by a normal third stage of creep. The second constant creep rate corresponds to the normal second stage.

Compression creep tests (made in specially adapted equipment which is described and illustrated) confirmed the occurrence of the 'ageing' period, which lasted longer under compression-creep than under tension-creep conditions.

Metallurgical changes associated with the creep characteristics are discussed.

By comparison with the average of published data for bar material of similar composition, the austenitic steel tubing, when tested at 1050° and 1100°F. (565° and 593°C.) showed lower yield strength, creep strength (for a rate of 10^{-6} per hr.) and rupture strength (at 10,000 hours in tension).

Rapid-Heating Tests on Inconel

G. J. HEIMERL, I. M. KURG and J. E. INGE: 'Tensile Properties of Inconel and RS-120 Titanium Alloy Sheet under Rapid-Heating and Constant-Temperature Conditions.'

Nat. Advisory Committee for Aeronautics, Tech. Note 3731, July 1956; 29 pp.

Further to preliminary data reported in 1955 (see abstract in *Nickel Bulletin*, 1956, vol. 29, Nos. 1–2, p. 17), this paper gives final results on sheet heated to failure at uniform temperature rates from 0·2°F. to 100°F. per second, under constant tensile-load conditions. Comparisons are made with conventional elevated-temperature tensile properties for the respective materials, and the possibility of predicting yield and rupture temperatures with temperature-rate parameters is studied. The work is part of a research designed to develop information on the strength of materials which may be used for missiles and aircraft structural applications, involving rapid-heating service conditions.

Effects of Radiation on Metallic Materials

See abstract on p. 30.

Oxidation of Metals and Alloys

K. HAUFFE: 'Oxidation of Metals and Alloys.'

Published by *Springer-Verlag, Berlin*, 1956; 389 pp.

An extensive treatment of the subject, presented in a classification determined by the nature and mechanism of oxidation in varying conditions, and illustrated by typical examples of the respective phenomena. The treatise includes reference to the oxidation characteristics of nickel and of its alloys with chromium, carbon, molybdenum, platinum and silver.

Protection of Molybdenum against Oxidation

J. J. HARWOOD: 'The Protection of Molybdenum against High-Temperature Oxidation. A Survey of the Problem and Progress.'

43rd Ann. Technical Proceedings, Amer. Electroplaters' Soc., 1956, pp. 78–90.

The lack of resistance to oxidation characteristic of molybdenum at temperatures above about 540°C. is a major obstacle hindering the full utilization of the mechanical properties of this metal, which would otherwise render it outstandingly suitable for high-temperature service. The nature of the attack, and means for preventing it, have already been the subject of intensive study in several countries; it is the purpose of this paper to bring together the evidence which has thus been accumulated and to indicate the stage of progress which has been reached.

The requirements which must be met by any coating which will form a surface barrier and thus inhibit oxidation are listed: resistance to oxidation, thermal shock, impact, erosion and fatigue, and an adequate degree of ductility at working temperatures. A review is made of the types of test which are in use to assess the protective materials in these respects.

The review is devoted, in the main, to a consideration of the methods which have been proposed for prevention of oxidation. The effects producible and the degree of protection afforded are discussed in relation to the use of self-regenerative scales, e.g., molybdates formed by oxidation of nickel or cobalt-molybdenum alloys, and coatings on molybdenum-base materials (e.g., coatings of ceramic materials, of molybdenum disilicide, metallic coatings deposited by cladding, spraying or electroplating, diffusion coatings, and chromizing).

The information available shows that the major stumbling block to the use of some of the methods which would prevent oxidation lies in the difficulty of securing adequate resistance to high-velocity impact.

It is concluded that the most successful coating compositions yet developed centre on the nickel-chromium alloy system. Both electroplated chromium-nickel layers and sprayed nickel-chromium alloys containing silicon and boron have shown the ability to protect molybdenum up to about 1090°C., and sprayed mixed-silicide layers also appear promising. The suitability of such protective methods should be determined by engine tests. Of the systems so far examined, only ceramic and molybdenum-silicide coatings offer promise for use at still higher temperatures. The review is documented with references to the major literature.

Electrodeposition of Chromium on High-Alloy Materials

See abstract on p. 35.

Materials for High-Temperature, High-Pressure Steam Service: Review

H. S. BLUMBERG: 'Metallurgical Considerations of Main Steam Piping for High-Temperature, High-Pressure Service.'

Amer. Soc. Mechanical Engineers, Paper 56-A-157, Nov. 1956; 23 pp. + figures.

The author emphasizes the inter-relationship between the metallurgist and the steam-plant mechanical engineer, and urges closer co-operation, in the interests of translating fundamental metallurgical knowledge, into terms which will ensure that it is intelligible to, and usable by, engineers.

To this end, a comprehensive survey of this field is made, from the standpoint of the 'application metallurgist'. The paper presents:

(*a*) the views of the author regarding the broad approach which should be made to the selection of materials for high-temperature, high-pressure steam-power plant and the study of their behaviour under service conditions,

(*b*) a review of the compositions and properties of steels currently used by American engineers for various purposes in steam-power plant,

(*c*) a critical appraisal of the potential usefulness of 'super alloys' for high-pressure, high-temperature steam piping,

(*d*) details of the programme being followed in selecting materials for use in the Eddystone unit of the Philadelphia Electric Company, which is to operate under conditions involving temperatures of 1200°F. (650°C.) and pressure of the order of 5,600 p.s.i.

Austenitic Steel Piping in Steam-Power Stations

F. P. FAIRCHILD: 'Eight Years of Experience with Austenitic Steel Piping Materials at Elevated Steam Conditions.'

Amer. Soc. Mechanical Engineers, Paper 56-A-181; 7 pp. + figures.

In three generating stations of the Public Service Electric and Gas Company, New Jersey, U.S.A., austenitic chromium-nickel steel piping is in service in the main steam systems of seven turbine-generator units, the first of which has been operating, in elevated-temperature steam conditions, since 1948. The type of steel used is niobium-stabilized '18-8', and in all some 280 tons of such material are installed in these stations. Records show that practically no trouble has been encountered except at points where the austenitic steel is joined to piping or other attachments, by welding.

This paper is designed to give perspective to the present status of this development, by presentation of a factual record of experience, in the power stations mentioned, with heavy-wall austenitic steel piping materials.

Typical weld failures have been examined, and it has been found that most of these (which, in total, are relatively few in number) were due to the fact that the joining had been done by methods which have since been superseded by improved techniques.

Among the most significant facts which have been learned as a result of the eight years' experience is the importance of completely avoiding stress raisers, by correct design of components of steam-piping systems, and of ensuring ample flexibility in the design of the piping system and its supports. The need for competent supervision and training of welders and of inspection during welding is also urged.

New techniques which have been developed in connexion with welding of austenitic steels include:

(1) a first-pass welding technique which avoids the use of a backing ring, and results in a smooth, crack-free surface on the inside of the pipe, thus eliminating formation of stress raisers,

(2) closer control of chemical composition of the deposited weld metal, with respect to its ferrite content,

(3) solution heat-treatment of welded joints, to ensure maximum ductility in the weld and the heat-affected zone.

Points which require further study include improved inspection methods, matching of the properties of the welds and the parent materials, tests for identification of crack-sensitive material, and the development of manufacturing techniques for consistent production of non-crack-sensitive material.

Ferritic-Austenitic Weld Joints in Steam Plant

J. T. TUCKER and F. EBERLE: 'Development of a Ferritic-Austenitic Weld Joint for Steam Plant Application.'

Welding Jnl., 1956, vol. 35, Nov., pp. 529S-40S.

Economic considerations involved in boiler design have led to the combined use of austenitic stainless steels and low-alloy ferritic steels in superheaters, re-heaters and main steam lines, where high pressures and temperatures above 1000°F. (540°C.) are involved. Due to differences in the thermal-expansion and thermal-conductivity properties of the two types of material, a complex stress condition is set up and when such dissimilar joints are subjected to repeated heating and cooling cycles the high thermal-expansion stresses, combined with metallurgical changes occurring at elevated temperatures, may result in unsatisfactory service life.

This paper refers to thermal-cycling tests made in the laboratories of Babcock and Wilcox Company, in conditions duplicating, as closely as possible, operating conditions existing in the main steam line of the boiler of a central power station. The nature of the failure of dissimilar welds of varied types, in these conditions, was closely investigated, and the significance of the following factors was studied in relation to susceptibility to weld failure:—holding time at temperature, stress-oxidation at constant temperature, cyclic stressing in the absence of oxygen, upper temperature of thermal cycling, post-weld heat-treatment.

Based on the observations made, a thermal-cycling tension test on tensile specimens containing dissimilar welds was selected as being a simple and inexpensive

method of evaluating such joints, and as giving results which could, with some measure of confidence, be translated into actual service conditions. (The investigation also included tests on various composite tube connexions which have been developed as a means of providing better resistance to the effects of thermal cycling, but it was concluded that this type of joint is not significantly more satisfactory than standard welds between dissimilar metals made with 18–8 chromium–nickel–iron electrodes.)

Results obtained in the various tests referred to above indicated that remedial measures must be sought along the following lines:

(1) prevention of oxygen at the weld interface, by covering that highly stressed zone with an oxygen barrier, to obviate stress-oxidation effects liable to initiate cracking in the ferritic steel adjacent to the weld interface,

(2) use of low-carbon ferritic weld metal, which lessens carbon migration, a method which has been successully used in attaching austenitic-alloy hanger lugs to ferritic superheater tubing,

(3) reduction of the differential-expansion stresses at the junction of the dissimilar materials, by using a weld metal having a coefficient of thermal expansion approaching that of the ferritic metal of the joint.

Examination of various materials which, as weld metals, would satisfy the above conditions, led to development of austenitic electrodes which will give weld metal highly resistant to oxidation and have a coefficient of thermal expansion similar to that of the ferritic material involved. A composition of nickel 50, chromium 10, + niobium-tantalum, balance iron, gave specially good results, and an Inconel electrode also proved satisfactory. Joints made with these electrodes, between 2¼ per cent. chromium-molybdenum steel and niobium-stabilized 18–8 chromium–nickel steel, satisfactorily withstand cyclic conditions of temperature and stress such as would be involved in the steam-boiler service envisaged.

Ferrite in Stainless-Steel Weld Metal: Measurement and Calculation

W. T. DELONG, G. A. OSTROM and E. R. SZUMACHOWSKI: 'Measurement and Calculation of Ferrite in Stainless-Steel Weld Metal.'

Welding Jnl., 1956, vol. 35, Nov., pp. 521S–8S.

The usefulness of controlled amounts of ferrite in austenitic weld metal, as a means of controlling cracking, has been increasingly realized during recent years: the Schaeffler constitutional diagram, developed in 1947, has been widely used as an aid to selection of correctly balanced structures in various types of austenitic steel electrodes.

The present paper reports measurements, by means of the Magne Gage, of the ferrite contents of more than 600 weld pads, comprising a wide range of size, type and coating. Comparisons of the values found by this means, with ferrite contents calculated according to the Schaeffler diagram, indicate that the Magne Gage is a useful and reliable instrument for this purpose. The test is simple and inexpensive, and provides a means for check tests by different laboratories. It is considered that, if used according to the procedures described in the paper, this method could form the basis of standard procedure for measurement and specification of the ferrite content of weld metal.

Such discrepancies as were found between Magne Gage readings and ferrite contents calculated according to the Schaeffler diagram indicated the need for some revision of the diagram, in particular to allow for the nitrogen content of the steel. A 'nickel equivalent' for nitrogen was therefore experimentally established and a modified constitutional diagram embodying this correction is proposed.

Nickel-Alloy Wires: Properties and Uses

See abstract on p. 39.

Nickel-base Sparking-Plug Alloys

See abstract on p. 38.

Complex Corrosion-Resisting Steel

M. G. FONTANA: 'New High-Strength Stainless Steel.' *Industrial and Engineering Chemistry*, 1956, vol. 48, Dec., pp. 53A–54A.

Notes on the properties of a steel designated by the Alloy Casting Institute CD4MCu. The following range is given as the preferred composition: carbon 0·04 max., nickel 4·75–6.00, chromium 25–27, molybdenum 1·75–2·25, silicon 1 max., manganese 1 max., per cent., balance iron.

The steel is aged, preferably to a hardness below 325 Brinell, by heating in the range 700°–900°F. (370°–480°C.). A table in this article, showing mechanical properties of two production heats made in different foundries, indicates that a good degree of ductility is obtained at a Brinell hardness of 300, with tensile strength of the order of 140,000 p.s.i. (62·5 tons per sq. in.) and yield strength about 100,000 p.s.i. (44·5 tons per sq. in.). If a lower hardness is required the material can be used in the solution-quenched condition, without ageing.

Results of boiling 65 per cent. nitric-acid tests show satisfactory resistance to corrosion, and the chemical stability of the alloy is further confirmed by the report of resistance to 10 per cent. and 50 per cent. sulphuric acid and 0·5 per cent. hydrochloric acid, at room temperature. In all these media the new steel showed better resistance to corrosion than 18–8 chromium–nickel steel.

Corrosion of Stainless Steel in Nitric and Nitric/Sulphuric Acids

C. P. DILLON: 'Corrosion of Type 347 Stainless Steel and 1100 Aluminium in Strong Nitric and Mixed Nitric-Sulphuric Acids.'

Corrosion, 1956, vol. 12, Dec., pp. 623t-6t.

Interstate Commerce Commission regulations permit the use of steel shipping containers for storage and transport of mixed nitric/sulphuric acids when the

composition of the acid falls within the ranges

up to	10%	water,	10%	sulphuric acid min.	
,,	15%	,,	15%	,,	,,
,,	20%	,,	20%	,,	,,
,,	38%	,,	62%	,,	,,

A commercially available mixed acid containing nitric acid 85, sulphuric acid 13·5, water 1·5, per cent., was found, however, to cause severe corrosion of steel tanks, and a tank clad with 18-8 niobium-stabilized steel, used as an alternative, also failed, after 12 months' service. The attack was characterized by severe corrosion of the top and walls of the tank, with slighter attack on the bottom, under copious coarse crystalline deposits of sulphates of chromium, nickel and iron.

The investigation made to determine the nature and cause of the corrosion was extended to the study of the behaviour of the stainless steel and of aluminium in mixtures of sulphuric and nitric acids.

The results of the tests (of which details are given) indicated that the attack of the stainless-clad tank was caused by vapour-phase corrosion by the fumes of the mixed acid. It is concluded that the resistance of austenitic stainless steel of that composition must be suspect at concentrations in excess of 95 per cent. total acidity, since, under quiescent conditions, it may become subject to severe vapour-phase attack. Such attack may not occur in shipping containers, because of the stirring and mixing of the solution occurring during transport or other movement. In both laboratory and field experience a high aluminium alloy (No. 1100) has been found to be satisfactory: this material is unaffected, in either liquid or vapour-phase exposure, at total acidities above 95 per cent., but is corroded in the liquid phase at total acidities below that value.

Stress Corrosion in Hydrofluoric Acid

H. R. COPSON and C. F. CHENG: 'Stress-Corrosion Cracking of Monel in Hydrofluoric Acid.'
Corrosion, 1956, vol. 12, Dec., pp. 647t-53t.

In discussing stress-corrosion cracking of high-nickel alloys, O. B. J. FRASER, in 1944, included data showing that Monel was susceptible to that type of failure in hydrofluosilicic acid, but it was believed at that time that the alloy was resistant to cracking in hydrofluoric acid. It was then thought also that all stress-corrosion cracking in Monel and other high-nickel alloys was intergranular, and that trans-crystalline cracking in these materials was confined to fatigue failures or other types of mechanical breakdown where corrosion was not involved. In 1948, however, transgranular fracture of K Monel bolts in hydrofluoric-acid vapour was observed, and since that date laboratory investigations have been carried out to ascertain the conditions in which high-nickel materials are susceptible to failure in such media.

The tests have been made on materials of the types shown in the table below.

In addition to determination of the effects of basis composition, the investigation covered a study of the effect of impurities in the acid, e.g., of silicon tetrafluoride, and the influence of minor constituents, such as silicon, in susceptible alloys. Test conditions included:

(1) exposure, in hydrofluoric-acid vapour, of U-bend specimens, tested in softened, cold-rolled, age-hardened, and welded conditions. (Tests made on all the materials listed in Table I),

(2) exposure of U-bend specimens of Monel and K Monel in hydrofluosilicic-acid vapour,

(3) total-immersion tests of Monel and K Monel in (*a*) 48 per cent. hydrofluoric acid, (*b*) 30 per cent. hydrofluosilicic acid, and (*c*) mixtures of those two acids.

The results of these tests (which are correlated with observations made in connexion with the case histories reported) confirmed that stress-corrosion cracking of the high-nickel alloys is likely to occur in moist aerated hydrofluoric-acid vapour, but that cracking is unlikely under total immersion conditions.

The number and path of the stress-corrosion cracks are influenced by composition of the alloys, and by cold work, heat-treatment, magnitude of the stress present, and time and conditions of exposure. Cracking is most prone to occur where rates of corrosion are high, such as in moist, aerated vapour, an observation which suggested that damage by occluded hydrogen might be a significant factor. Experiments in which it was shown that U-bend specimens of age-hardened K Monel could be made

Nominal Composition of Materials used in Stress-Corrosion Tests

Material	C %	Ni %	Cu %	Si %	Mn %	Fe %	Cr %	Al %	Ti %	Nb %
K Monel ..	0·15	66	29	0·50	0·75	0·9	—	2·75	0·5	—
Monel ..	0·15	67·0	30·0	0·1	1·0	1·4	—	—	—	—
Nickel ..	0·06	99·4	0·1	0·05	0·25	0·15	—	—	—	—
Duranickel ..	0·17	93·7	0·05	0·5	0·3	0·35	—	4·4	0·4	—
Inconel ..	0·08	77	0·2	0·25	0·25	7	15	—	—	—
Inconel X ..	0·04	73	0·05	0·4	0·5	7	15	0·9	2·5	1

to crack by cathodic charging with hydrogen support this interpretation.

With regard to practical methods for obviating stress-corrosion cracking under unfavourable conditions such as those considered in the paper, the following observations are made:

'One means of avoiding stress-corrosion cracking is to eliminate the tensile stresses. With proper attention to design, applied loads can usually be kept low. Internal stresses can be relieved by a full anneal and slow cooling, but full annealing is not usually required. In the case of Monel, stress-relieving by heating for one hour at 1100°–1200°F. (595°–650°C.) and slow cooling is recommended. In tests by O. B. J. FRASER in 22 per cent. hydrofluosilicic acid at 149°F. (60°C.), cold-drawn Monel tubing cracked in 328 hours, but stress-relieving at 1000°F. (538°C.) served to prevent the cracking.

'Another means of avoiding stress-corrosion cracking is to alter the environment. In the present case, cracking of Monel is most likely to occur when corrosion rates are high. Non-ferrous metals such as Monel are, however, normally specified only when they show good resistance to corrosion. In any case, making conditions less corrosive should be doubly beneficial by both avoiding the cracking and decreasing the weight losses. Avoiding aeration and keeping the metal totally immersed are both beneficial. In one application continuous flushing with nitrogen has served to prevent the cracking.'

Corrosion by Naphthenic Acid

W. A. DERUNGS: 'Naphthenic Acid Corrosion: an Old Enemy of the Petroleum Industry.'

Corrosion, 1956, vol. 12, Dec., pp. 617t–22t.

The term 'naphthenic acids' is a collective name for organic acids present in various crudes. It has been proved that, whilst minor quantities of other organic acids are included, the main acids from naphthenic-base crudes are saturated ring structures containing acid groups. The circumstances in which naphthenic-acid corrosion occurs are analogous to those causing sulphur corrosion, but a practical differentiation between the two types of attack can be made by examining the nature of the corrosion. The main features of deterioration undergone as a result of attack by the two media are briefly discussed.

Information available from all sources indicates that the rate of corrosion by naphthenic acid is dependent on the concentration of the acids in the oils, the operating temperature, the velocity of the fluid handled, and the activity of the naphthenic acids. Corrosion may be lessened by removal or neutralization of the naphthenic acids, by modifying the velocity of the fluid, and by selection of the most resistant materials for construction of the plant. Methods for removal or neutralization of the naphthenic acids are discussed, and some recommendations on modification of velocity are made, but the critical absolute velocity values below which corrosion rates remain low are not yet known. These vary with temperature.

With regard to materials of construction the following observations are made:

'*Unalloyed Steel*

Mild steel is not attacked by naphthenic acid-containing oils below a temperature of 220°C. (430°F.). In the temperature range of, say, 220°–400°C. (430°–750°F.) mild steel may be attacked up to 20 mm./yr. (0·8 in./yr.), depending on operating conditions. Extra-low-carbon steel (e.g., Armco iron) has proved to be somewhat more resistant than normal mild steel.

'*Cast Iron*

Cast iron has been found to be up to 15 times more resistant than mild steel. Alloyed cast irons show no better resistance to corrosion than unalloyed types.

'*Low-Alloy Steels*

Under conditions of relatively high fluid velocity chromium-molybdenum steel (Cr 5, Mo ½%) may be much more resistant than mild steel, but except perhaps for furnace and heat-exchanger parts the usefulness of this material is doubtful, since it is often very irregularly attacked, with a pitting form of corrosion.

'*Stainless Steel*

The 12 per cent. chromium steel should not be used in the presence of naphthenic acids. The 18–8 chromium-nickel types are often quite resistant under conditions of low fluid velocity, but may undergo severe pitting. The 18–8–3 Mo steel has, however, been found to be highly resistant in all the conditions studied, as are the 25–20 and 25–12 chromium-nickel steels.

'*High-Nickel Alloys*

With the exception of Monel (containing about 30 per cent. of copper), all this group of alloys are highly resistant to naphthenic acid.

'*Copper and Copper Alloys*

Unsuitable for contact with naphthenic acids.

'*Aluminium and Aluminium Alloys*

Aluminium has been found highly resistant to corrosion, under all conditions, but its use to date has been restricted by mechanical properties and weldability. Copper-containing alloys, e.g., of the Duralumin type, are unsuitable.'

Stress Corrosion of Austenitic Steel in Strainers of Pulp Mills

I. D. G. BERWICK: 'A Case History of Stress-Corrosion Cracking of Austenitic Stainless Steel.'

Corrosion, 1956, vol. 12, Dec., pp. 634t–6t.

The author discusses the corrosion of strainer plates used, in pulp mill digesters, to handle calcium-based sulphite liquor containing 1·1 per cent. of combined sulphur dioxide and 7·5 per cent. total sulphur dioxide, circulated at about 144°C. The pH of the

liquor averaged 3·0. Each strainer consisted of a cast frame of Type 317 steel* and a facing plate of Type 316 steel*, tackwelded to the frame. The facing plates were bent along two lines, to give a U-shaped section, and were perforated with a large number of drainage holes.

After service periods as short as six weeks the plates pitted and became coated with a very adherent calcium-sulphate/wood-resin scale. In addition, the face plates suffered severe bursting failure at the bends. The metal appeared to have become completely weakened at the points of failure.

The liquor handled was of a composition which would favour stress-corrosion of material in a susceptible condition, and fabricating operations used on the face plates had undoubtedly set up internal stresses, which had been intensified by stitch-welding of the plates to the frame. External stresses arising from flexing of the plates in service or from scale build-up on the frame had also played a part. Pitting corrosion observed on the failed plates, although not directly connected with the stress-corrosion cracking, had possibly also had a stress-raising influence.

Remedial measures adopted, which have eliminated stress-corrosion failures and reduced pitting, consisted in the use of the higher-molybdenum steel Type 317 for the facing plates as well as the frames and application of a stress-relief treatment at 1550°-1600°F. (840°-870°C.) for 30 minutes, followed by air- or furnace-cooling. As an additional precaution, the plates are now being welded to the frames in three separate sections, thus eliminating the bending operation.

* Steel	C %	Cr %	Ni %	Mo %
316	0·08 max.	16-18	10-14	2-3
317	0·08 max.	18-20	11-15	3-4

Chemical Analysis of Nickel-containing Materials

See abstract on p. 30.

Accelerated Testing of Metallic Surfaces

See abstract on p. 36.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks.*

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